Work System Analysis: The Key to Understanding Health Care Systems

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Abstract

Many articles in the medical literature state that medical errors are the result of systems problems, require systems analyses, and can only be addressed with systems solutions. Within that same body of literature is a growing recognition that human factors engineering methods and design principles are needed to reduce medical errors and, hence, increase patient safety. Work system analysis methods, which are based on industrial and human factors engineering tools, have much to contribute toward patient safety, specifically because of their focus on systems. They offer principles and methods for analyzing systems, which, if followed, should help health care administrators and clinicians properly analyze their units or facilities, and should lead to more robust patient safety interventions. In this paper, steps for executing a work system analysis are provided. To facilitate comprehension of the steps, the medication administration system is used as an example.

Introduction

Many articles in the medical literature state that medical errors are the result of systems problems, require systems analyses, and can only be addressed with systems solutions.[1–5] However, few articles have been written that specifically explain how to analyze a system so that systemwide problems can be uncovered and solutions implemented; this paper does just that.

System analysis can help manage and reduce risks by identifying hazards so they can be controlled through good design. That is, in order to improve safety, quality, performance, and comfort, a good place to start is by analyzing the involved systems so they can be improved. The key to improving safety and reducing risk is through good system design, which can only be achieved though a complete understanding of the system. To understand the system, it is essential to know how to analyze it. Industrial and human factors engineering work system analysis methods provide a set of tools that can be used to analyze health care systems.

Chapanis states that human factors engineering "discovers and applies information about human behavior, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use."[6, 7] Following many years of successful implementation in a diverse array of fields, human factors tools and methodologies are now gaining acceptance in health care. This is most notable in

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the two recent Institute of Medicine (IOM) reports, *To Err Is Human*[8] and *Crossing the Quality Chasm,*[9] which claim that human factors methods should be used to address patient safety and quality-of-care issues. Since then, a growing number of examples in the literature show that human factors tools and methods are being accepted and used in health care settings.[10–16]

The increase in the use and popularity of human factors in health care can be traced to successes of human factors in fields such as mining,[17] nuclear power,[18] manufacturing,[19, 20] and aviation.[21, 22] Although these industries have successfully used human factors for decades, adoption of human factors tools and methodologies in health care has been slow. Human factors engineering methods and design guidelines have been slowly adopted in health care for some of the same reasons that health care is thought to have safety problems. Most prominent is the expectation that health care professionals will perform perfectly, which has resulted in a heavy focus on addressing individual performance versus system design. Cook and others[12] wrote, "The conventional view is that the [health care] system is safe by design but can be degraded by the failure of its human components." From this perspective, all medical errors and adverse events are somebody's fault. In other words, a health care professional is more likely to get "redesigned" (retrained) than the system. Also working against a systems view is that "for physicians, the ever-present threat of malpractice litigation provides an additional incentive to keep silent about mistakes."[4] These are system problems, and they contribute to the slow diffusion of human factors engineering methods and design guidelines throughout health care delivery systems precisely because they are antithetical to system analysis and design.[23, 24]

Although this medical culture has existed for many years, health care has come to a proverbial fork in the road regarding patient safety and errors. This fork was inspired by research that uncovered a disturbing numbers of errors in health care.[10, 14, 25, 26] Currently, health care professionals are beginning to recognize the need to find tools to address the current patient safety problems—as well as patient safety problems that are yet unknown. This search has opened the door for the use of human factors engineering tools and methods in health care. For example, Weinger et al.[16] noted that "human factors research techniques, such as task analysis and workload assessment, may provide useful objective data on the structure and characteristics of the anesthesiologist's job and the impact of design innovations on task performance." In the same domain, Cook and Woods[27] evaluated how anesthesiologists reacted to a new patient-monitoring technology. Anesthesiologists adapted the new technology to suit their needs using two methods: making the system compatible with their current cognitive strategies, and adapting their strategies for completing tasks to accommodate the constraints of the new system. That study showed how studying human-technology interactions can yield important information about the design of health care systems. Surgical errors have also been studied using human factors engineering techniques,[11] though the most common reason for using human factors methods in health care has been to study the possible impacts of new technologies, especially information technology, on patient safety.[13, 28–32]

Importantly, system analysis techniques have also begun to uncover and solve health care safety problems. In one example, Patterson et al.[33] analyzed the work of nurses using barcoded medication administration technology. The system analysis uncovered new side effects of the technology, including unanticipated routes to adverse drug events. Using a structured work system analysis, Hallock et al.[34] used a sociotechnical system analysis to analyze and improve the safety of outpatient diagnostic testing systems at a large urban outpatient health care facility. Using many work system analytical tools, including variance matrices and variance control tables, hazards were discovered and solutions were proposed to reduce or eliminate the problems affecting the safety and quality of the preanalytic, analytic, and postanalytic phases of diagnostic testing. Clearly, many different human factors tools and methodologies, including system analysis, can be used to improve health care delivery. As Nolan noted, "The physician who is willing to learn about the nature of systems, how to control them, and how to improve them can significantly influence medical systems."[3]

Work system analysis

Overview

System analysis has much to contribute to patient safety, specifically through its study of organizational and work systems. In general, a system analysis yields an understanding of how a system works and how different elements in a system interact. This facilitates system design and system redesign, and aims to improve the interface between components of a system in order to enhance the functioning of each individual component in the overall system. Adopting a systems approach to error reduction requires a shift from blaming individuals for errors to analyzing systems to uncover design flaws, thus moving from addressing problems reactively (i.e., after problems occur) to proactively preventing accidents through system analysis and design.

Although many different methods have been used to conduct system analysis in industry, few methods have been widely used in health care. System analysis methodologies include, among others, the macroergonomic analysis and design (MEAD),[35, 36] fault tree analysis,[37, 38] failure modes and effects analysis (FMEA),[39, 40] health care failure modes and effects analysis (HFMEA),[41] and probabilistic risk assessment (PRA).[42, 43] Each of these methods uses similar principles to analyze and determine the weaknesses of the system and facilitate its redesign. In the remainder of this paper, the main steps that these methods share are identified and explained in detail.

Key systems terms

Before presenting the main steps in a system analysis, an understanding of system terms must be developed. To facilitate reader comprehension of the terms and steps in the system analysis, the medication administration system will be used as an example throughout the remainder of the paper.

- **System element:** A system element is anything that is part of a particular system. Elements can include people, technologies, policies, lighting, furniture, and jobs. In the case of the medication administration system, elements include the administering nurses, patients, medications, medication administration record (MAR), medication stock room, patient rooms, and identification bands.
- **System attribute:** System attributes are the perceived characteristics of the system. The medication administration system attributes could include "error-free," "time consuming," "chaotic," and "high quality."
- **System boundary:** System boundaries are zones between one system and another. These zones can be in time, space, process, or hierarchy.
    - **Temporal boundary:** A temporal boundary separates systems in time. For the medication administration system, a temporal boundary could be drawn between the first and second shift.
    - **Spatial boundary:** A spatial boundary separates systems in space. An example could be the medication administration system for one particular unit versus that of another unit.
    - **Process boundary:** A process boundary separates systems into adjacent component processes, also known as subprocesses. The medication use system contains component processes of ordering, transcribing, verifying, dispensing, administering, and documenting. An example of a process boundary might then be the boundary between the process of dispensing and delivering medications to the unit and the process of administering the medication.
    - **Hierarchical boundary:** A hierarchical boundary separates systems by their location in a hierarchy of systems. For example, the medication administration system exists within a larger system known as a unit. The unit exists within a larger system of a hospital. A hospital exists within a larger community health system.
- **System input:** A system input is anything necessary to energize the system. For medication administration, inputs include nurses who administer drugs, drugs, MARs, physician orders, and pharmacy dispensing. These elements are inputs because they are necessary for medication administration to take place.
- **Transformation:** Transformations are processes that turn inputs into outputs; they are actions in the system. The action of administering a medication to a patient is a transformation of an input (i.e., a medication) into an output (i.e., a medicated patient). However, many other transformations take place in the medication administration system. These include patient manipulations, patient monitoring, retrieving drugs from medication carts or cabinets, and reading MARs.

- **Outputs:** Outputs are the results of transformations. For example, the output of administering a medication is a medicated patient.
- **Unit operation:** A unit operation is a simple input-transformation-output process that does not contain any other input-transformation-output processes. It is the most basic component process of interest. For example, within the larger process of administering medications, which might have a process boundary that starts with a nurse examining a MAR and ends when the administration is documented, there are a number of unit operations. Each of the following actions is an example of a unit operation: check MAR, locate medication, compare medication to MAR, locate patient, identify patient, administer medication, and document administration.

Conducting a system analysis

What follows are detailed explanations of 10 steps common to the various system analysis methodologies. These steps, if followed, should help to ensure an effective analysis and thus effective system redesign.

Step 1

Decide what system will be the subject of the analysis. This determination dictates the direction of the remaining steps. For example, this might be the entire medication system, from physician order to documented administration, or just the ordering system; it might be the nurse shift transition, or just the communication system between unit nurses and the charge nurse.

Step 2

Produce a preliminary work system map. This often-overlooked step is critical to the success of the entire analysis. The purpose of this map is to identify inputs and outputs relevant to the system, which facilitates the identification of people who should be represented on the analysis team (step 3). Furthermore, by understanding the inputs and outputs of the system being studied, the system boundaries can be determined (step 5).

A work system map is similar to a workflow diagram, but it contains additional detail. A traditional workflow diagram presents steps in a process, including decision points. A work system map also provides further detail for each step in the process, by identifying at least six additional pieces of information:

- What technology is used
- What policies and rules (internal to the unit and external to the organization) are involved in determining how, when, why, or where the step is executed
- What supervision is involved in the step

- What environmental factors (e.g., lighting, noise, vibration) might affect the step or how it is executed
- What other people might influence the execution of this step or determine whether the step takes place
- What information is needed for the execution of this step

This preliminary work system map can be assembled through brainstorming or short observations. Because it is preliminary and designed for identifying team members and system boundaries, it does not have to be exhaustive at this point. It will be modified throughout the work system analysis.

Step 3

Use the preliminary work system map to determine who should be represented on the team that will carry out the analysis. The importance of good representation cannot be overestimated. Without representation from all involved stakeholders, it is likely that the team will lack the expertise necessary to correctly analyze the system, identify hazards, and control hazards. Stakeholders will likely include sharp-end employees as well as blunt-end employees, like supervisors and managers. One way to identify who should be represented is to consider groups and individuals who (a) communicate with frontline employees, (b) provide inputs, (c) receive outputs, and (d) assume responsibility for various parts of the process. The team must also contain at least one expert in system analysis to guide the process. Once the team is assembled, its first task is to examine the preliminary work system map to make sure all stakeholders are represented.

Step 4

The assembled team should conduct an initial scan of the system. An initial scan has two scanning components. First, the team studies the preliminary work system map and gauges its accuracy. Several questions can guide this process:

- What other people take part in this system? Where do they come from: other units or temporary agencies? Are there other people who provide information relevant to the system?
- What other technologies, tools, or equipment are used in this process? Where do they come from? Who is responsible for maintaining them?
- What other policies or regulations are relevant to the steps in this process? Who develops them? Who enforces them?
- What other organizational variables, such as reward systems or communication systems, affect the performance of this process? Who is in charge of these?
- What other jobs or tasks affect the performance of the steps in the process? Who carries out these jobs? Who is responsible for them?
- What other environmental factors impact the system?

- What people, technologies, tools, equipment, processes, and/or jobs are impacted by the process under study?

The team members can also informally interview stakeholders and observe steps to help complete this part of the scan. If the process of agreeing on the work system map leads to the identification of additional stakeholders, representatives of those stakeholders should be invited to join the team.

The second component of the initial scan is to "scan the horizons." The team will investigate any pending decisions, policies, or regulations, internal and external to the organization, that could impact the system. Similarly, the team will want to determine if any internal process changes are planned and if any new technologies are scheduled for implementation. This information must be incorporated into subsequent redesign plans. If this "horizon scan" is not completed, the entire system redesign plan could be rendered ineffective because it may not integrate with pending changes.

Step 5

Put boundaries on the system under study. The team needs to determine process, hierarchical, temporal, and spatial boundaries. If these boundaries are too narrow, the team may miss important variables that contribute to the performance of the system; if they are too broad, the analysis may take up unnecessary resources. Setting the boundaries too broad is less dangerous than setting them too narrow. Setting broad boundaries usually results in increased analysis time. Setting boundaries too narrow can result in misrepresentation of the system, which can lead to poor or dangerous redesign ideas. For example, bounding the medication administration process to include only the day shift may not capture differences between shifts (e.g., level of supervision or number of medications administered), which would limit the effectiveness of redesign proposals. Similarly, if the medication administration system is bounded to include only the steps from reviewing the MAR to documenting the medication, important inputs from pharmacy processes would likely be overlooked. In that case, hazardous processes in the pharmacy that lead to administration errors might be left unchanged.

Step 6

Performance expectations for each step in the system should now be determined. Performance expectations are quantitative or qualitative statements that describe what outcomes should come from each unit operation, component process, or overall process studied in the system. For example, certain processes should be done safely, some should be done quickly and safely, and others may have production and quality goals. The team should do its best to determine specific, measurable performance goals. For example, instead of stating that a step should be done "safely," the performance expectation might be "zero medication administration errors." Similarly, instead of stating that a process should be completed "quickly," the team could determine that the process should be completed "within 15 minutes of receiving the order." A process can have one or

more performance expectations. Performance expectations are important because they provide the team with measures by which to evaluate the performance of the current and redesigned systems. They also provide criteria on which to evaluate the impact of failures, weaknesses, or hazards identified in the data analysis.

Step 7

The team should begin formal data collection to revise and update the work system map, gauge the current performance of the system, and determine baseline measures that will be used to evaluate the effectiveness of the redesign. Data can be collected through time studies, administrative databases, maintenance records, structured observations of the process, and interviews of the involved stakeholders. Interviews should be used to collect details about the system elements and attributes, and to reconcile and/or clarify data collected from observations. This data collection step is typically the lengthiest part of the system analysis, because extensive data collection is required for an accurate map. Depending on the system being studied, this could take days, weeks, or months. Questions and guidelines presented in steps 2 and 4 should be used to develop the data collection tools for observers and interviewers. Once the team puts together the work system map, stakeholders outside of the analysis team should be invited to examine the map, to make necessary changes, and to validate its accuracy.

Step 8

The team can begin analyzing the collected data. The purposes of the analysis are to (a) identify weaknesses, variances, and any series of events that could cause the system to fail; and (b) prioritize the identified problems for redesign. This can be executed qualitatively, quantitatively, or using mixed methods, depending on the system analysis method used (e.g., failure modes and effects analysis, sociotechnical system analysis, probabilistic risk assessment). Typically, a combination of analytical methods will provide better analysis than any one method, because one method may compensate for the weaknesses of another. Readers are advised to consult the references provided, as well as other sources, for details on using specific methods. It is important to understand that using quantitative analytical methods does not increase the objectivity of the analysis. Objectivity only increases to the extent that the analysis is based on valid and reliable data, which is true for both qualitative and quantitative analysis.

Step 9

Once hazards (i.e., causes of failure modes or variances) have been identified, control strategies should be developed. These strategies should be based on the hierarchy of hazard control, which states that the best hazard controls are those that completely eliminate the hazard. The next best option is to guard against the hazard, and the two least effective controls are training and warning. To help facilitate the development of effective control strategies, a hazard-control matrix should be developed. A hazard-control matrix, which is based on the variance control table,[35] has 10 headings in the top row, as shown in the example in Table 1.

Table 1. Hazard-control matrix: example of one hypothetical hazard in the diagnostic testing process

Hazard?	Step in the process where hazard occurs?	Cause(s) of the hazard?	Step in process hazard first noticed?	Who currently controls the hazard?	Current control activities?	Proposed control activities?	Criteria for knowing variance is controlled?	Personnel responsible?	Status of control methods?
Wrong test ordered by physician	Diagnostic test order	Poorly designed order form or wrong test chosen by physician	Sample analysis, or possibly not until results come back or patient is notified	Nobody is responsible at this time. Patient or physician is most likely to see the mistake once results come back.	None	Activate the lab ordering module in the order entry system.	Study will be initiated by the director of laboratory quality to determine change over time in rate of incorrrect tests ordered.	Director of Laboratory Quality	1/1/03: Steering committee approved the change and the study. 1/22/03: Study design approved. 2/4/03: Baseline meaures being collected.

All of the hazards identified for control are then listed underneath the first heading, and the rest of the cells are filled in. This matrix displays the identified problems, current system status, and proposed problem solutions. The matrix also facilitates progress tracking by displaying solution status and the names of individuals responsible for the solutions.

Step 10

The final step in a work system analysis is to conduct a system analysis on the redesign hazard-control ideas that the team develops. This should be done before redesigns are implemented so the team is confident its proposed redesign ideas do not unintentionally reduce the effectiveness of the system nor create new safety problems. Each redesign idea or hazard-control idea should subsequently be subjected to a full system analysis (i.e., develop a new process map with the redesign idea, compare it with the original system design, identify hazards, see if they need to be controlled). Once completed, pilot testing and implementation can begin.

Conclusions

The Joint Commission on Accreditation of Healthcare Organizations (JCAHO) currently requires all hospitals to conduct at least one annual risk assessment for high-risk processes and redesign the process to minimize the likelihood of failure.[44] To meet this requirement, a health care organization must identify a target system and conduct a system analysis on it, precisely what has been discussed in this paper. However, the JCAHO standard is only a minimum requirement, and requires only one such analysis to be conducted each year. But a work system analysis is warranted anytime that a health care organization intends to change a system, implement a new technology, update a process, or modify job requirements. Such an analysis should provide details regarding the current state of the system, which is necessary to accurately identify problems and their causes before patient or employee safety is affected. Once problems and causes are identified and prioritized, system analysis techniques can be used to determine effective approaches to redesign the current system into a safer one. This paper provides detailed steps as a guide through the process of conducting a system analysis. With this information, health care administrators and clinicians should be able to more confidently proceed with transforming their organizations into safe systems.

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References

1. Reason J. Human error: models and management. Br Med J 2000;320:768–70.
2. Nolan TW. System changes to improve patient safety. Br Med J 2000 Mar 18;320(7237):771–3.
3. Nolan TW. Understanding medical systems. Ann Intern Med 1998 Feb 15;128(4):293–8.
4. Leape LL. A systems analysis approach to medical error. J Eval Clin Pract 1997;3(3):213–22.
5. Leape LL. Error in medicine. JAMA 1994 Dec 21;272(23):1851–7.
6. Chapanis A. Some reflections on progress. Paper presented at the Human Factors Society 29th Annual Meeting; 1985; Santa Monica, CA.
7. Sanders MS, McCormick EJ. Human factors in engineering and design. New York, NY: McGraw-Hill, Inc; 1993.
8. Kohn LT, Corrigan JM, Donaldson MS, editors. To err is human: building a safer health system. A report of the Committee on Quality of Health Care in America, Institute of Medicine. Washington, DC: National Academy Press; 2000.
9. Hurtado MP, Swift EK, Corrigan JM, editors. Crossing the quality chasm: a new health system for the 21st century. Washington, DC: National Academy Press; 2001.
10. Barker KN, Flynn EA, Pepper GA, et al. Medication errors observed in 36 health care facilities. Arch Intern Med 2002 Sep 9;162:1897–903.
11. Calland JF, Guerlain S, Adams RB, et al. A systems approach to surgical safety. Surg Endosc 2002 Jan 8;16:1005–14.
12. Cook RI, Render M, Woods DD. Gaps in the continuity of care and progress on patient safety. BMJ 2000 Mar 18;320:791–4.
13. Karsh B, Beasley J, Hagenauer M. Are electronic medical records associated with improved perceptions of the quality of medical records, working conditions, or quality of working life? Behav Inf Technol 2004;23(5)327–35.
14. Leape LL, Bates DW, Cullen DJ, et al. Systems analysis of adverse drug events. JAMA 1995 Jul 5;274(1):35–43.
15. Nolan T. System changes to improve patient safety. Br Med J 2000 Mar 18;320(7237):771–3.
16. Weinger MB, Herndon OW, Gaba DM. The effect of electronic record keeping and transesophageal echocardiography on task distribution, workload, and vigilance during cardiac anesthesia. Anesthesiology 1997 Feb 22;87:144–55.
17. Trist EL, Susman GI, Brown GR. An experiment in autonomous working in an American underground coal mine. Hum Relat 1977;30(3):201–36.
18. Meshkati N. Human factors in large-scale technological systems accidents: Three Mile Island, Bhopal, Chernobyl. Industrial Crisis Quarterly 1991;5:131–54.
19. Punnett L. Ergonomic stressors and upper extremity disorders in vehicle manufacturing: cross sectional exposure-response trends. Occup Environ Med 1998;55:414–20.
20. Marras WS, Lavender SA, Leurgans SE, et al. The role of dynamic 3-dimensional trunk motion in occupationally-related low-back disorders—the effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. Spine 1993;18(5):617–28.
21. Sexton JB, Thomas EJ, Helmreich RL. Error, stress, and teamwork in medicine and aviation: cross sectional surveys. Br Med J 2000;320:745–9.
22. Thomas EJ, Helmreich RL. Will airline safety models work in medicine? In: Rosenthal MM, Sutcliffe KM, editors. Medical error: what do we know? What do we do? San Francisco: Jossey-Bass; 2002. pp. 217–34.
23. Beasley JW, Escoto KH, Karsh B. Design elements for a primary care medical error reporting system. Wis Med J 2004;103(1):56–9.
24. Hamilton K, Karsh B, Beasley J. Medical error reporting system design: multiple user considerations and their implications. Paper presented at the Human Factors and Ergonomics Society 47th Annual Meeting, 2003; Denver.
25. Leape LL, Brennan TA, Laird N, et al. The nature of adverse events in hospitalized patients: results of the Harvard Medical Practice Study II. N Engl J Med 1991;324:377–84.

26. Kaushal R, Bates DW, Landrigan C, et al. Medication errors and pediatric inpatients. JAMA 2001 Apr;285(16):2114–20.

27. Cook R, Woods DD. Adapting to new technology in the operating room. Hum Factors 1996 Dec;38(4):593–613.

28. Berg M, Langenberg C, vd Berg I, et al. Considerations for sociotechnical design: experiences with an electronic patient record in a clinical context. Int J Med Inform 1998 Oct–Dec;52(1–3):243–51.

29. Berg M. Patient care information systems and health care work: a sociotechnical approach. Int J Med Inform 1999;55:87–101.

30. Kushniruk AW, Patel VL, Cimino JJ. Usability testing in medical informatics: cognitive approaches to evaluation of information systems and user interfaces. J Am Med Inform Assoc 1997:218–22.

31. Stricklin MLV, Struk CM. Point of care technology: a sociotechnical approach to home health implementation. Methods Inf Med 2003;42(4):463–70.

32. van Veelen MA, Meijer DW, Goossens RHM, et al. Improved usability of a new handle design for laparoscopic dissection forceps. Surgical Endoscopy and Other Interventional Techniques 2002 Jan;16(1):201–7.Patterson ES, Cook RI, Render ML. Improving patient safety by identifying side effects from introducing bar coding in medication administration. J Am Med Inform Assoc 2002 Apr 16;9(5):540–53.

33. Patterson ES, Cook RI, Render ML. Improving patient safety by identifying side effects from introducing bar coding in medication administration. J Am Med Inform Assoc 2002 Apr 16;9(5):540-53.

34. Hallock M, Alper S, Karsh B. Process improvement in an outpatient clinic: application of sociotechnical system analysis. Paper presented at Human Factors and Ergonomics Society; 2003 Oct; Denver.

35. Hendrik HW, Kleiner BM. Macroergonomics: an introduction to work system design. Santa Monica, CA: Human Factors and Ergonomics Society; 2000.

36. Pasmore W. Designing effective organizations: the sociotechnical systems perspective. New York, NY: John Wiley and Sons; 1988.

37. Roberts N. Fault tree handbook. Washington, DC: Government Printing Office; 1992.

38. Rankin JE, Tolley GO. Fault tree analysis. Beckley, WV: Dept. of the Interior, National Mine Safety Academy; 1978. (For sale by the Superintendent of Documents, U.S. Government Printing Office)

39. Stamatis D. Failure mode and effect analysis: FMEA from theory to execution. Milwaukee, WI: American Society for Quality; 1995.

40. Sheff R, Marder R. The step-by-step guide to failure modes and effects analysis. Marblehead, MA: HCPro, Inc.; 2002.

41. VA National Center for Patient Safety. Healthcare failure mode and effect analysis course materials (HFMEA™). Available at: http://www.patientsafety.gov/HFMEA.html. Accessed March 3, 2004.

42. Kumamoto H, Henley EJ. Probabilistic risk assessment and management for engineers and scientists. 2nd ed. New York, NY: IEEE Press; 1996.

43. Marx DA, Slonim AD. Assessing patient safety risk before the injury occurs: an introduction to sociotechnical probabilistic risk modeling in health care. Qual Saf Health Care 2003;12(Suppl II):ii33–ii38.

44. Joint Commission for Accreditation of Healthcare Organizations. Patient safety standards—hospitals. Available at: http://www.jcrinc.com/subscribers/perspectives.asp?durki=2973&site=10&return=2897. Accessed April 22, 2004.